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An Alternative Representation of a Simulated Human Body

by Benjamin J. Flanders

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14. ABSTRACT
The purpose of this memorandum report is to document how a representation of the human body was created for the FragFly model. The body was formed by performing the following actions on existing human body models: separation, overlapping, addition, and reduction. This report describes each of these actions in detail and why they were needed.

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1. Introduction

A common representation for the human body for the purpose of simulating injury comes from the Computer Man[1] model developed by the U.S. Army Ballistics Research Laboratory (now the U.S. Army Research Laboratory) in 1978. The model consists of over 450,000 grid cells arranged in 113 cross sections.[2] Each cell is assigned an anatomical description so that cells can be grouped together to form bones, organs, muscles, etc. The incapacitation model Operational Requirements-based Casualty Assessment (ORCA)[3] uses this model to determine injury from insults to the body from fragments and bullets. An alternative representation was introduced by the Integrated Casualty Estimation Methodology (ICEM)[4] model. In essence, the ICEM body model is a "skin" for the Computer Man model. This representation, which is composed of a vertex and face structure that forms the ICEM body model, can be found in the ICEM data files. A graphical representation of the ICEM body can be seen in figure 1 (body parts are separated for clarity only; the ICEM body model does not include the gaps that are seen in the figure).

[1]Stanley, C.; Brown, M. *A Computer Man Anatomical Model*; ARBRL-TR-02060; U.S. Army Ballistics Research Laboratory: Aberdeen Proving Ground, MD, 1978.

[2]Eycleshymer, A. C.; Shoemacker, D. M. *A Cross-Section Anatomy*; D. Appleton and Company: New York and London, 1911.

[3]Soldier Survivability and Vulnerability Team, Ballistics and NBC Division. *Operational Requirements-Based Casualty Assessment: ORCA Analyst's Manual*; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, August 2005; draft.

[4] U.S. Army Natick Soldier Research, Development & Engineering Center. http://nsrdec.natick.army.mil/media/fact/techprog/ICEM.PDF (accessed 12 August 2013).

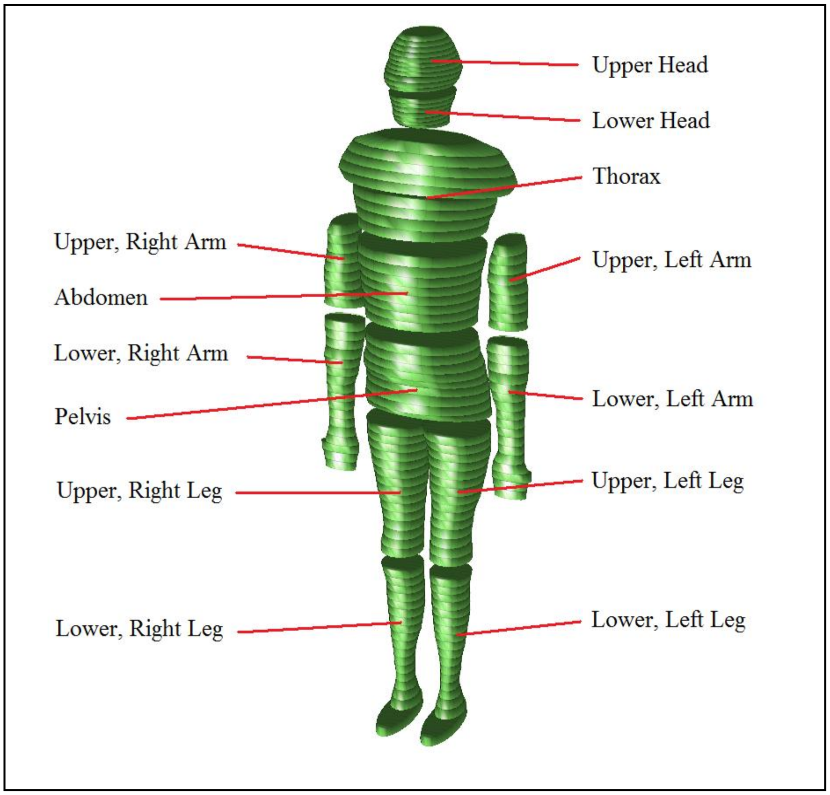

Figure 1. Graphical representation of the ICEM body model with body parts separated and labeled.

In total, the ICEM body model is composed of 7616 vertices that form 13,544 triangular faces. It groups the vertices and faces into 13 parts (identified in figure 1). As a skin layer, insults such as fragment strikes may intersect the ICEM model without necessarily intersecting the underlying Computer Man cells. This is because the ICEM body model fits each cross section of Computer Man with an ellipsoid.

The ICEM body model was modified to suite a recently developed incapacitation model, FragFly, in four ways:

1. **Separation** – Some body parts were separated to allow for independent movement. For example, the foot was separated from the lower leg, a distinction that is not made in the ICEM body model.

2. **Overlapping** – The vertices associated with some body parts were extended so that they can create an overlap with certain adjacent parts. This was done to eliminate excessive gaps from posing the human figure.

3. **Addition** – Additional surfaces were added so that gaps would not be created during body part rotation about joints.

4. **Reduction** –To decrease the overall face count of the human body, a reduction algorithm was used. Significant reductions will lead to a noticeable decrease in the overall runtime of the FragFly model.

The 7616 vertices of the ICEM body model can be seen in figure 2 (a), and the result of the modifications that led to the FragFly body model can be seen in figure 2 (b). It is important to note that only the vertices of the ICEM body model were used in order to arrive at the FragFly body model. The faces of the ICEM body model were ignored. This allowed for a freedom of choice in all ways in which the ICEM body model was modified.

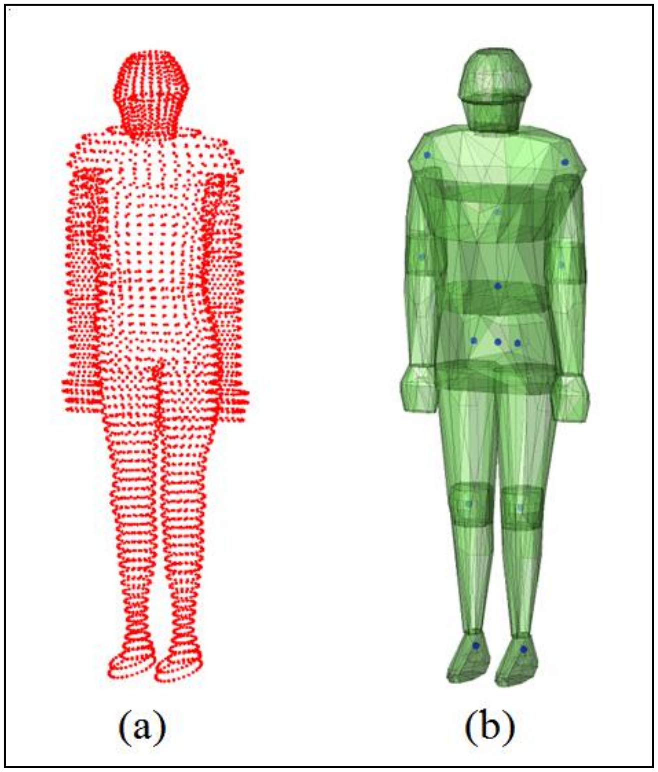

Figure 2. Body model representations. (a) The vertices of the ICEM body model. (b) The FragFly body model.

A summary of the two body models appears in table 1.

Table 1. Body model data.

Body Model	No. of Body Parts	No. of Faces	No. of Vertices	Total Volume (cm^3)
ICEM	13	13,544	7,616	101,587.15
FragFly	16	1,242	657	107,563.94

Figure 3 (a) details the parts of a body and (b) identifies the joints that were added to the FragFly body model. Table 2 provides a description of the parts and joints.

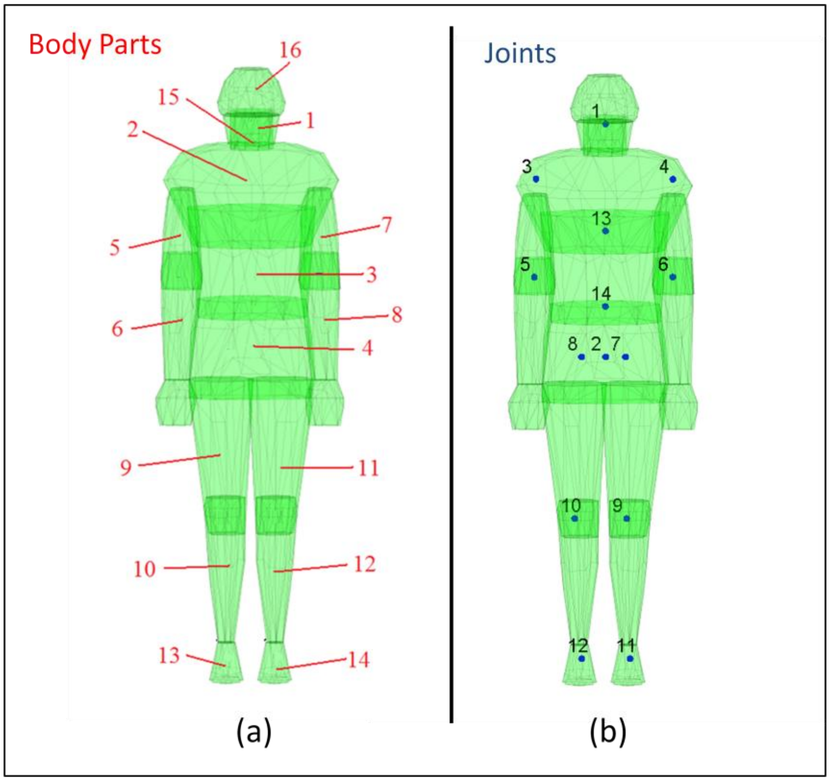

Figure 3. (a) FragFly body model with body parts labeled. (b) Joints of the FragFly body model labeled.

Table 2. Descriptions of body parts and joints.

Component		Joint
ID	Description	Description
1	Lower head	Neck
2	Thorax	Pelvic
3	Abdomen	Right shoulder
4	Pelvis	Left shoulder
5	Upper right arm	Right elbow
6	Lower right arm	Left elbow
7	Upper left arm	Left hip
8	Lower left arm	Right hip
9	Upper right leg	Left knee
10	Lower right leg	Right knee
11	Upper left leg	Left ankle
12	Lower left leg	Right ankle
13	Right foot	Thoracic vertebra 2
14	Left foot	Thoracic vertebra 10
15	Neck	—
16	Upper head	—

Each of the modifications will be discussed separately in the remaining sections.

1.1 Separation Modification

As mentioned earlier, some body parts were separated to allow independent movement. For instance, the feet in the ICEM body model are considered part of the lower leg. When posing the body, it may be desirable to have a more natural orientation of the body parts.

In addition, later during the Reduction Modification, a convex hull will be formed around each body part. For body parts with severely convex regions, this could lead to the inclusion of unnecessary volume. Not only does it not "look right," but it will lead to many false-positive collision detections.

Consider constructing a convex hull around a lower leg as seen in figure 4 (a). A lower leg of the ICEM body model is shown in figure 4 (a). Figure 4 (b) shows a convex hull around the entire leg. Figure 4 (c) is the result of partitioning the foot from the lower leg and forming a convex hull around the two components. The volume of (a) is 4286.92 cm^3; the volume of (b) is 8607.60 cm^3; and the volume of (c) is 4658.34 cm^3.

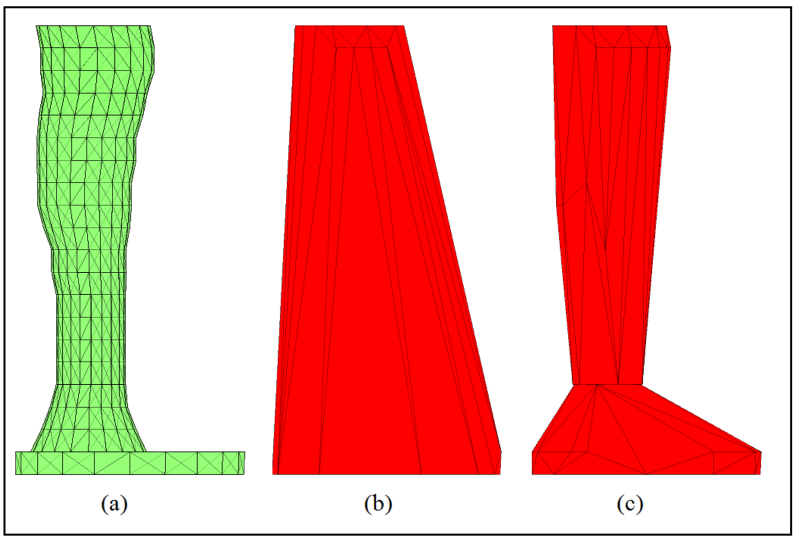

Figure 4. (a) ICEM lower leg. (b) Convex hull of the ICEM lower leg.
(c) Two convex hulls of a separated ICEM lower leg.

The hands of the FragFly body were "separated" from the lower arms; however, they do not move independently of the lower arm (i.e., no wrist joint was defined due to the complexity of lower arm movements such as turning the palms of the hand front to back). Therefore, they do not have a separate designation from the lower arms. A fragment that strikes the hand will be counted as a lower-arm hit.

1.2 Overlapping Modification

The human body in the FragFly model is posable in that body parts are intended to be rotated about joints. All rotations are assumed to be rigid. Thus, tendons, skin, and muscles are not stretched or deformed. Because the human body has a skeletal frame with few joints and long bones, this is mostly a fair representation of the body. Rotations of the ICEM body parts, however, can create some odd outcomes. The upper and lower arms of the ICEM model meet at a common plane. Regardless of the elbow joint location, a "gap" will be created for any elbow rotation of the lower arm as the two planes separate.

To mitigate this behavior, certain adjacent body parts were designed to overlap. This was done by redefining the set of vertices that belong to certain body parts. For instance, even though the ICEM body model specifies which of the vertices in figure 2 (a) belong to the lower arm, this set can be expanded by including a few more cross sections of the upper arm. Likewise, the upper arm can include a few layers from the lower arm. The result of this overlap can be seen in figure 5, where the left side of the FragFly body is shown and the left arm has been rotated 0° (a), 45° (b), 90° (c), and 135° (d). This creates an ambiguity in determining wound tracks; however, a well-defined algorithm should eliminate any redundancies.

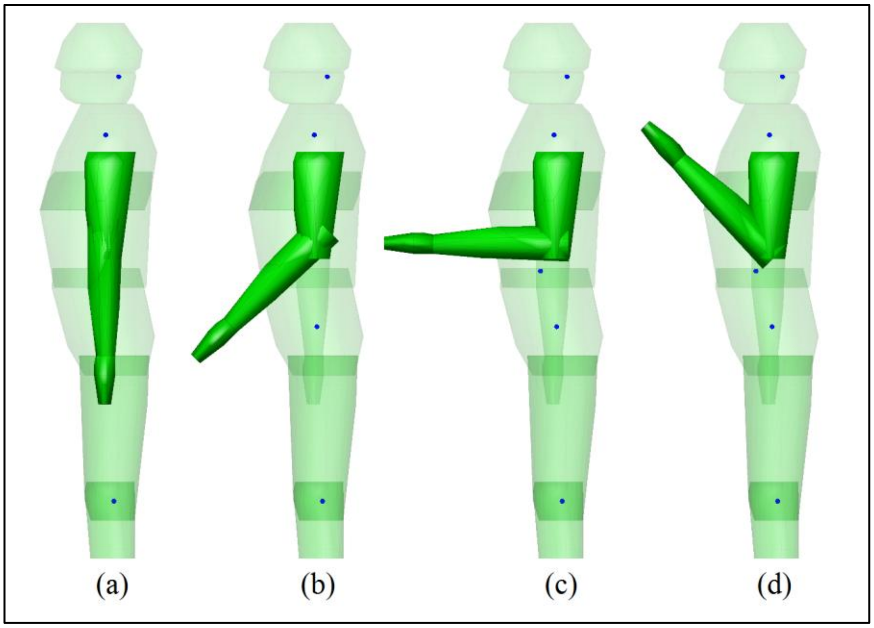

Figure 5. Left arm rotations: (a) 0°, (b) 45°, (c) 90°, (d) 135°.

The FragFly model expanded nearly all the body parts to create overlaps between the upper and lower arms and legs, and between the thorax, abdomen, and pelvis.

1.3 Addition Modification

Only one body part was added to the body model. The ICEM body model does not include any "neck" surfaces because the lower head meets the thorax at a common plane. This means that if

the head is rotated so that the target was looking “up,” a gap will be created between the head and thorax. Figure 6 (a) shows the left side of the FragFly body with no head rotation. Figure 6 (b) shows a neck rotation without any neck surfaces. Without a neck, a gap is created. This can create many problems for determining fragment impacts. On one hand, fragments may pass through the gap wherein they should have impacted the body. On the other hand, exposing the bottom side of the lower head may create a wound track that begins at a point internal to the head without passing through any other tissue. To eliminate these problems, a cylinder was added, which can be seen in figure 6 (c) (identified as “Neck”). The neck is rigidly attached to the thorax and contains no flexibility that a typical human neck would have.

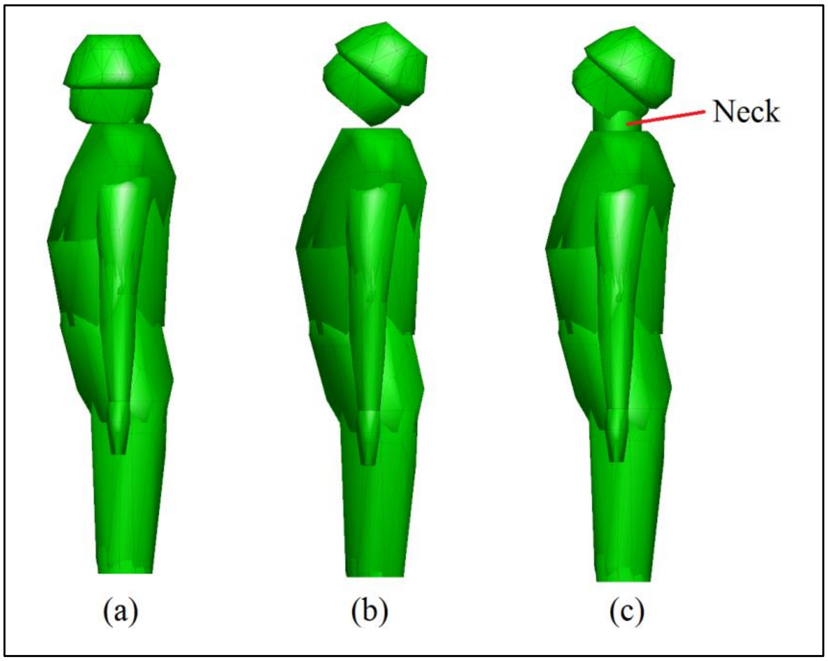

Figure 6. FragFly body model in (a) standard posture, (b) with a neck rotation (no neck), and (c) with neck.

1.4 Reduction Modifications

In its current form, the FragFly model detects collisions of fragments against the surfaces of the target by first testing for collisions with bounding boxes of individual body parts. If a fragment’s path intersects a body part’s bounding box, all the surfaces associated with the body part are tested one at a time. For high surface counts, this can lead to lengthy runtimes of the collision detection algorithm. Thus, a surface reduction measure was taken to reduce the runtime of FragFly.

The surface reduction measure consists of two steps, both of which eliminate vertices from the body and redefine the face structure. The first step was to form a convex hull around each body part. This automatically caused a reduction in the number of vertices because vertices in slightly convex regions will be subsumed in the convex hull. This method was performed in MATLAB using the “convhull” method. As stated earlier, a new face structure was created.

The second step in the process was the application of the MATLAB function “reducepatch” to the convex hull structure. The MATLAB function eliminated vertices based on an undocumented algorithm. The reducepatch algorithm then reformed a new face structure.

Figure 7 demonstrates the effects that the reduction process on the set original set of ICEM body model vertices in figure 2 (a). The original set is labeled “ICEM.” After the first step, when the convhull function is used, the ICEM set is reduced to the set labeled “convex hull.” The second step reduces the convex hull set further until one is left with the set labeled “FragFly.”

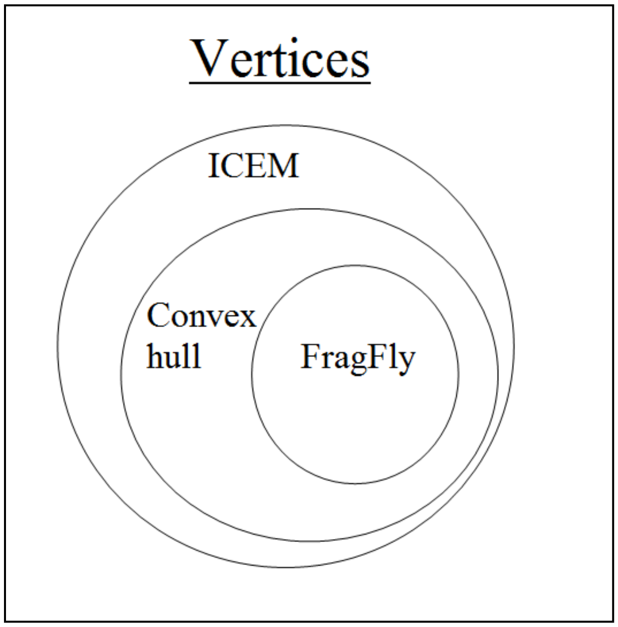

Figure 7. A Venn diagram that illustrates the relationship that exists between the vertices that belong to the ICEM set, the convex hull set, and the FragFly set.

The most obvious concern is eliminating too many vertices. Removing too many vertices can lead to a misrepresentation of the target wherein the target will have a reduced volume or size. This would lead to “false misses,” where a fragment that missed the reduced body would have struck the ICEM body. Ideally, the reduction would make near misses only affect superficial layers of skin, which would have an insignificant impact on the overall incapacitation calculation.

How can one determine if a reduction is acceptable? One way is to consider the overall loss of volume. This can be somewhat complicated in the two-step process because the first step of forming a convex hull around the body parts will actually increase the volume of the body part. The volume associated with the ICEM set in figure 7 is actually smaller than the volume associated with the Convex hull set in the same figure. Table 3 calculates the enclosed volume of each body part of the ICEM body model (labeled “ICEM BodyVolume”). Additionally, two

other volumes are calculated. The first volume labeled simply "Convex Hull Volume" is the volume calculated after the convhull is used on each body part, but before the "reducepatch" function is called. The second volume, labeled "FragFly Volume," is the volume of the body for the FragFly body model (after both reduction steps have been taken). Both volumes are larger than the original. Overall, the FragFly is only about 6% larger than the original.

Table 3. Body part volumes.

Body Part	ICEM Body Volume (cm^3)	Convex Hull Volume (cm^3)	FragFly Volume (cm^3)
Head/neck	6,765.534	6,888.817	6,601.606
Thorax	22,078.193	23,938.479	23,010.839
Abdomen	22,078.193	23,938.479	23,010.839
Pelvis	17,736.533	18,937.412	18,074.839
Arms	9,533.163	11,151.169	10,469.328
Legs	23,395.529	27,964.182	26,396.482
Total body	101,587.146	112,818.537	107,563.935

Another approach is to make measurements of the elements in the set (ICEM - FragFly), that is the vertices in the ICEM set that are not in the FragFly set in figure 7. To illustrate the set (ICEM - FragFly), consider the plot in figure 8. Figure 8 combines the vertices of the ICEM body (figure 2 [a]) overlaid on top of the surfaces of the FragFly body (figure 2 [b]) into one plot. The ICEM vertices are represented by red dots. To aid the reader, a close-in view of the plot is included. Notice that the surface of the FragFly body contains some of the vertices of the ICEM body while others lay exterior to the body. The set (ICEM - FragFly) are all red dots that are visible outside of the body.

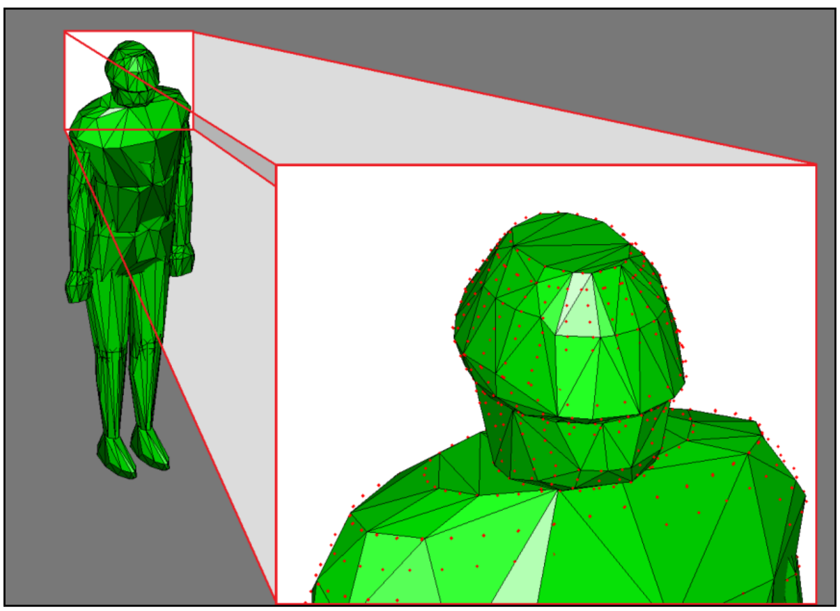

Figure 8. FragFly body model with ICEM vertices. Viewing pane (inset).

For each element in the set (ICEM - FragFly), which is a vertex, the metric "miss distance" is defined as the shortest distance between the vertex and the surface of the FragFly body model. Figure 9 shows a histogram of all miss distances. Notice that a vast majority of vertices are less than 5 mm from the FragFly body. This means that for most of the time, any wound track on the body will be short by at most 5 mm at the surface or skin layer of the body. This should make almost no difference in terms of incapacitation calculations. Note that the ICEM body model is actually larger than the Computer Man model because of the ellipsoid fitting that ICEM does to each cross section of the Compute Man model. This implies that the miss distances between the original Computer Man and the FragFly body model could be even smaller than what are seen in figures 9.

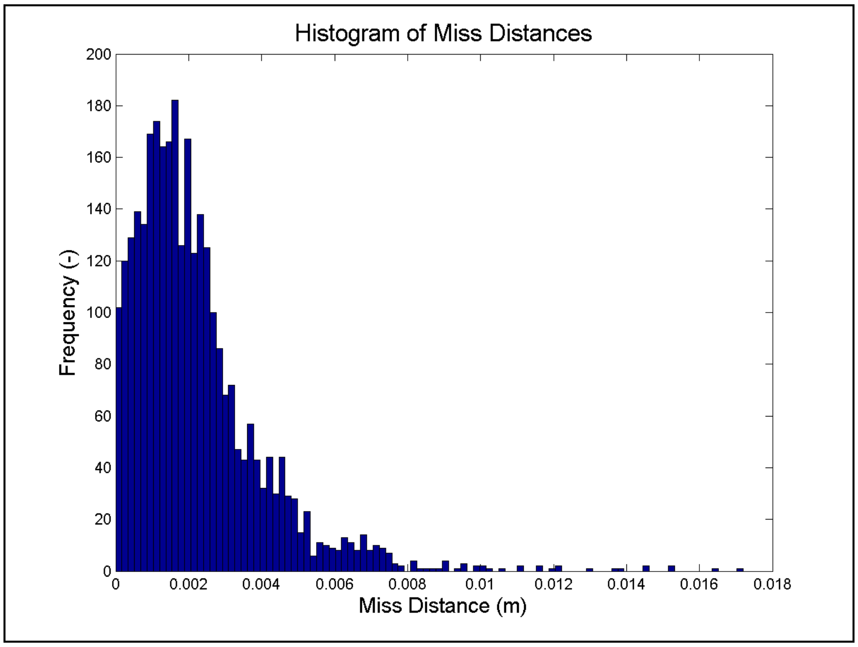

Figure 9. Histogram of ICEM vertex miss distance.

Figure 10 graphs the cumulative distribution function of the miss distances in figure 9. Two "data tips" are included. The data tips provide the values of the cumulative distribution function ("Y" values) at approximately 1 cm (center, top data tip) and 1.8 mm (left data tip). Approximately 99.4% of the miss distances are less than 1 cm. Over half of the miss distances are less than 1.8 mm.

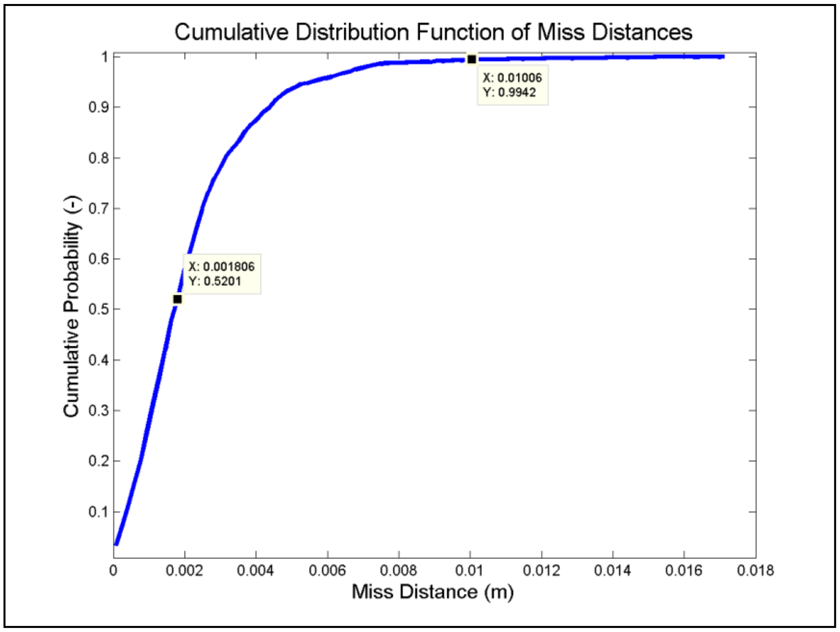

Figure 10. Cumulative distribution function of the miss distances.

The most dramatic comparison between the ICEM and FragFly body representations can be seen by looking at their face counts. Table 4 lists the number of faces for each body part.

Table 4. Body part face count.

Body Part	ICEM Face Count	Convex Hull Face Count	FragFly Face Count
Head/neck	1,640	1,212	248
Thorax	1,196	440	100
Abdomen	976	264	54
Pelvis	1,116	500	80
Arms	3,600	1,998	408
Legs	5,016	1,866	352
Total body	13,544	6,280	1,242

In summary, the number of faces in the ICEM body model has been reduced by nearly 92%. The reduction had little effect on “false hits” since the FragFly body is only 6% percent larger than the ICEM body model, and since most wound tracks are going to be short only by at most 5 mm or less at the skin, it should have no effect on incapacitation calculations.

2. Conclusion

The FragFly model requires a definition for a human body. The ICEM body model offers one definition. This body definition was considered inadequate because it did not allow for the articulation of the hands and feet, did not include neck surfaces, would create gaps for body part rotation about joints, and was too detailed for use in the FragFly model. The ICEM body was modified by separating body parts, including neck surfaces, overlapping of some adjacent body parts, and reducing the total number of faces.

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